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Holocene sea-level changes in the Malay-Thai Peninsula, a tectonically stable environment

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Abstract: The Malay-Thai Peninsula is part of tectonically stable Sundaland, which is the southeast corner of the Eurasian Plate. The Holocene sea-level changes in the region are deduced from a total of 200 dated shoreline indicators. Sea level reached a peak of about 5 m and about 4 m some 5,000 years and 6,000 years ago in Peninsular Malaysia and Thailand. This mid-Holocene transgression was followed by sea-level decrease that took place either gradually, or step-wise with thousand-year periods of stillstand, or more likely in a series of short to medium long periods of regressions and smaller transgressions. During one of the regressions, Late Holocene sea level probably dropped below current datum.

Shoreline indicators of pre Mid-Holocene age located between the latitudes of the Langkawi Islands and Phang Nga are anomalously high. These high elevations suggest geoidal relief of up to 40 metres between the northern and southern parts of Strait Malacca.

INTRODUCTION

The Malay-Thai Peninsula is a large portion of tectonically stable Sundaland. In the current, widely accepted theory of continuing plate motions, crustal stability is of course a relative notion, that is intuitively understood by structural geologists and tectonicists. In my experience, other scientists seem to visualise absolute crustal stability for such regions where vertical movements should also be nil. In all types of geological regions, be these orogenically active or stable, isostasy causes uplift or subsidence. The rates of crustal movements are generally distinctly different and, therefore, the effect of isostasy in a stable region is subdued. A tectonically stable region should have following characteristics.

(1) The region is composed mainly of outcropping pre-Tertiary and older rocks, or such rocks are submerged in shallow seas only.

(2) Any Tertiary or Quaternary sedimentary cover is thin, in the order of a few hundred metres.

(3) The Cenozoic sedimentary cover is still horizontal, or weakly deformed into basinal structures.

(4) No epicentres of strong earthquakes are located in a tectonically stable region. Weak earthquakes may take place where large reservoirs become filled or when enormous surficial mass movements occur. These quakes generally result from reactivation of existing zones of crustal weakness (such as faults) through large-scale interference by man.

(5) The region has no orogenic or andesitic volcanism; volcanic activity, if present, produces alkali basalt flows with little evidence of pyroclastic products.

(6) Any faulting is of the gravity or normal type. Drag folds may be associated with such faults, but wide-spread series of regular anticlines and synclines are absent, since a tectonically stable region reacts to lateral compression (generated by plate motions) as a single unit.

(7) Crustal deformation of tectonically stable regions takes place through slow uplift or subsidence of large areas as result of isostatic compensation. This results in gently tilted areas, and broad warps of the order of tens of kilometres across.

(8) Annual rates of crustal uplift/subsidence in tectonically stable regions are in the hundredths (or slower) of a millimetre; that at plate margins and in orogenic regions reach values of over a centimetre. Lateral plate motions have been measured to reach more than 10 cm per year.

All above cited characteristics apply to the Malay-Thai Peninsula and may be read or deduced from the regional geological maps (Geological Survey of Malaysia, 1985; Geological Survey Division, Department of Mineral Resources (Thailand, 1983) and from geological publications on the region.

For about 40 years field geologists have documented evidence of geologically young, raised shorelines in the region. Since the early seventies, organic material and beachrock representing former shorelines in Peninsular Malaysia were dated by radiocarbon and over 150 dates have been published. In Thailand similar efforts in the past ten years resulted in the publication of almost one hundred dates of past shorelines (see Sinsakul *et al.*, 1985; Sinsakul, 1990; Engkagul & Pramojanee 1991). Descriptions of these dates from Peninsular Malaysia are compiled in Yoshikawa (1987) and recent reviews of Quaternary shorelines were written by Tjia & Fujii (1989), Tjia (1991), and Kamaludin Hassan & Yunus Abdul Razak (1991). Many of the dated shoreline indicators from Malaysia consist of various species of rock-clinging oysters, and therefore, their positions with reference to former sea levels are certain to within the tidal range, which is generally about 2 metres. Since such oysters prefer the upper tidal zone, the uncertainty of their position with respect to former sea stands is less than a metre.

The relative tectonic stability of the Malay-Thai Peninsula, as argued above, implies that its dated shorelines represent the actual positions of past sea levels. Within the past 10,000 years (which is accepted as being the Holocene), slow isostatic crustal movements, if any, could not have exceeded a metre in elevation. For the purpose of this paper, this "possible maximum" value of isostatic crustal motion in the Peninsula can be ignored.

In this paper the probable sea-level changes in the Peninsula during the Holocene is presented after descriptions of the various shoreline markers that have been used. Sample descriptions are contained in Tjia *et al.* (1977) and the publications cited earlier. For completeness sake, the four groups of causes of sea level change are also reviewed. The substance of this particular section is taken from another paper (Tjia, 1990).

Sea level change

Long-term sea level change, as opposed to tidal or seasonal changes, may be attributed to four groups of causes, that is, (1) change of the water volume in the oceans, (2) change in the volume of the ocean basins, (3) change of the geoid (which is the water surface that everywhere is perpendicular to the direction of gravity), and (4) human activities.

(1) Change in the water volume

1.1. Glacial factor – During glacial periods water was extracted from the sea to develop glaciers. Meltwater from the glaciers returned to the sea during warm interglacial periods. During the Quaternary Era, or the last 1.8 million years of Earth's history, many glacial and interglacial intervals had alternated resulting in lowering and raising sea level perhaps as low as 130 m below and as high as 30 m above present sea level. The last Glacial Period reached its peak 18,000 years ago. During the period, sea level in Southeast Asia stood at least 100 m below present datum. At the peak of the Last Interglacial some 125,000 years ago, sea level reached 6 m above present sea position. It has been estimated that then sea temperatures were perhaps 1°C warmer. During glacials, global temperature may have been 5°C cooler. Especially on East Asian coasts, there is overwhelming evidence that 6,000-5,000 years ago sea level was again 5 to 6 metres higher than today.

1.2. Thermal factor – Temperature changes of sea water cause it to expand or to contract in response to warming or cooling, respectively. It has been calculated that a global warming of 1°C would cause sea level to rise 65 cm as result of expansion of all ocean waters. At the same time, global warming would also cause glaciers and ice sheets to melt. The West Antarctic ice sheet is mainly resting on the sea and is therefore most susceptible to warming of the ocean waters. During the Last Interglacial this ice sheet probably melted completely and accounted for the 6 metres high sea stand at 125 ka BP (Before Present; 0 Before Present = 1950 AD). However, it will take several hundreds to a few thousand years to completely melt the ice sheet.

1.3. Juvenile and Connate Waters – Water trapped in the interstices of sediments, or connate water, may be released mainly through compaction and heating. Volcanos produce large volumes of water, most of which consists of recycled surface waters. A small fraction is magmatic or juvenile water. In other words, throughout geologic history volcanic activity has been contributing to the water mass at the surface.

(2) Change in ocean basin volume

2.1. Isostasy – Geoscientists accept that beneath a relatively thin (about 150 km) rigid lithosphere, the Earth's upper mantle behaves as a viscous solid or rheid with the ability to flow under high pressure and high temperature operating over long periods. Changes of mass distribution within or upon the crust is compensated by flowage of heavy mantle material away from areas of subjected to loading. This compensation mechanism is called isostasy. Regions that during the Last Glacial were covered by 3 to 4 km thick ice sheets, such as the Baltic region and that of North America from the Great Lakes northward, have been rising isostatically more than a hundred metres since 10,000 years ago when the sheets retreated northward and eventually melted completely. Artificial lakes and reservoirs cause loading and are known to result in depressing broad regions containing the new water bodies. From such observations it is estimated that isostatic response to change in surficial mass distribution may begin to take place in about ten years.

2.2. Epeirogenesis – Slow vertical movements involving broad regions of the crust, a geological process called epeirogenesis, are attributed to phase changes, recrystallization, thermal convection currents, and other still unknown processes in the Earth's mantle. Rates of movements are probably hundredths to thousandths of millimetres annually (see Tjia, 1970). Such movements have been documented from geologically stable regions, such as the Thai-Malay Peninsula (Fig. 1). Epeirogenetic movements probably also take place in geological mobile regions, such as the Moluccas and the Philippines, but there more rapid crustal movements, the so called orogenetic movements, appear to have masked the effects of epeirogenesis.

2.3. Orogenesis – The same causes that result in epeirogenesis probably also result in the rapid vertical as well as lateral crustal movements known as orogenetic movements. Average rates range up to 10 millimetres yearly. The actual movements, however, are presumably spasmodic. This is suggested by the terrace-like appearance of reef terraces and recurrence intervals of earthquakes. An other difference from epeirogenesis is that orogenetic movements affect elongated zones near continental edges or along fracture zones. According to Plate Tectonic Theory, the rigid crust of about 150 km thickness (consisting of the actual Earth's crust of not thicker than 70 km and uppermost mantle), also known as the lithosphere, is composed of six major "plates", each moving as a unit. When two plates move rapidly away from each other, global sea level rises causing widespread transgressions. The stratigraphic record seems to substantiate this. Both, epeirogenesis and orogenesis cause changes in ocean basin volume.

2.4. Sedimentation – Epeirogenesis and especially orogenesis create relief that result in increasing the rate of sedimentation. Sediments entering the ocean basin change its volume. High relief also assists mass movements and by this process land-based material may be transferred into the oceans. In certain areas, high topography may change air current systems and regional climate. The climatic changes may contribute to more rapid denudation of the land and thus contribute to ocean basin change more effectively.

2.5. Organisms – Adverse changes in the marine environment may result in mass extinctions and contribute to faster sedimentation of organic matter that in turn changes the ocean basin volume. Such changes may also be expected from growth and decay of coral reefs.

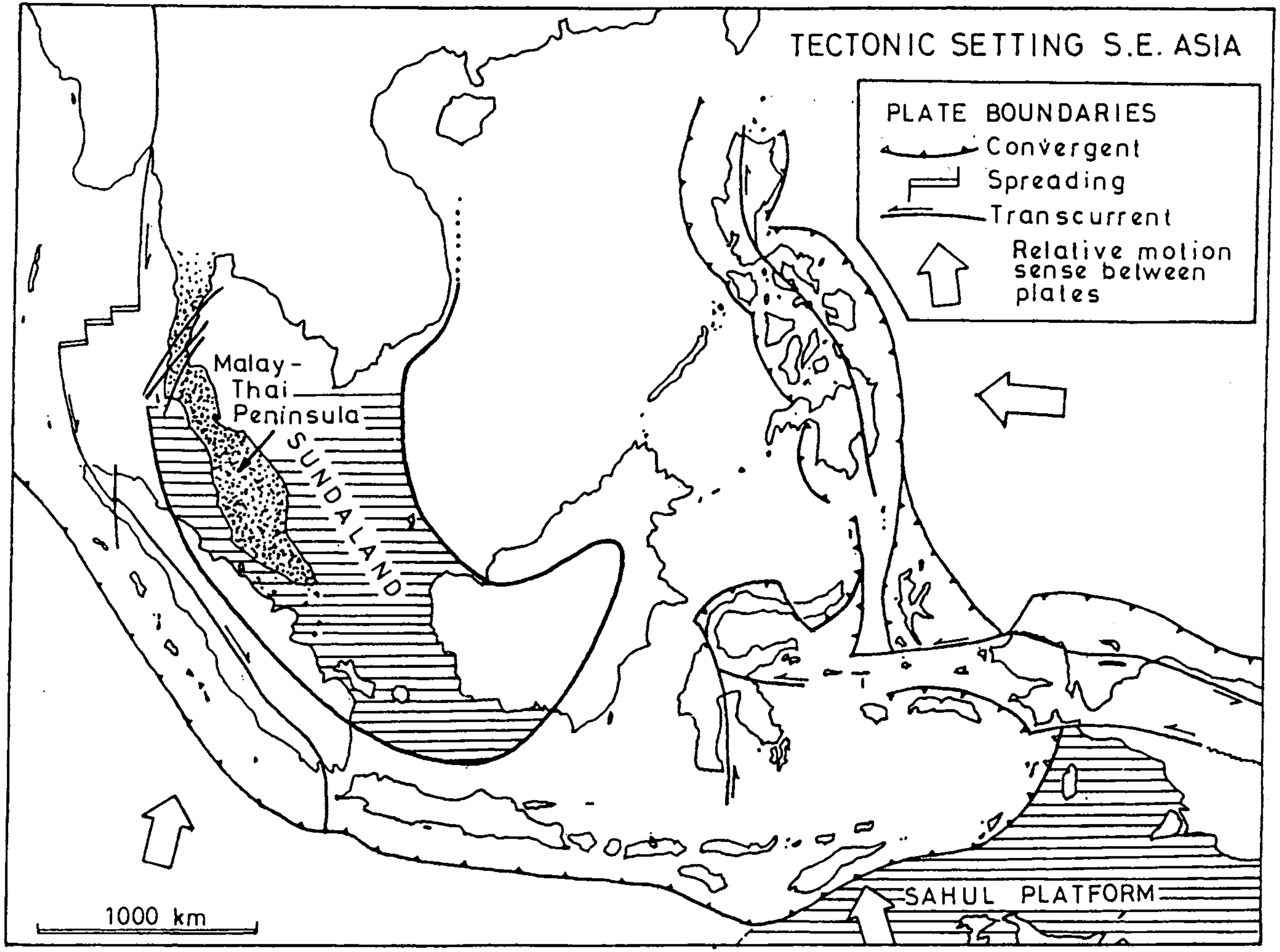

Figure 1: Geologically stable Sundaland and Sahul Platform, and the geologically mobile region between and around them.

2.6. Volcanism – Erupting volcanos transfer material from inside the Earth onto its surface. Part of the volcanic products is distributed over large regions and directly or eventually enters the ocean basin changing its volume. Coastal and oceanic volcanos change the ocean basin volume directly by their presence. Eventually, the topographic elevations created by volcanos will be partly compensated by subsidence through isostasy.

2.7. Extraterrestrial Matter – Cosmic dust continuously rains down. Since water constitutes 71 per cent of the Earth's surface, most of the cosmic matter settles on the sea floor. Cosmic dust forms part of the red clay found in deep-sea floors. The rate of red clay sedimentation is a mere millimetre each thousand years. However, cosmic dust and the occasional meteorite also contribute to changing the ocean basin volumes.

Indirectly large meteorites may have caused widespread climatic changes resulting in different precipitation patterns and catastrophic organic and physical changes. For instance, the rather sudden extinction of dinosaurs some 65 million years ago at the end of the Cretaceous has been attributed to a large meteorite (or a meteorite shower) impacting with Earth. The collision resulted in fire storms and prolonged dust storms that blocked out sunlight causing most vegetation to expire followed by extinctions of certain herbivores and carnivores. In more than a dozen localities worldwide, sediment representing the Cretaceous-Tertiary time boundary has been found to contain high proportions of iridium, uncommon in Earth material but usual in meteorites (Alvarez, 1987).

3. Geoid

The shape of the Earth as defined by the surface of the seas is the geoid. This surface is everywhere perpendicular to the direction of gravity. In the crust and mantle, material of different densities is distributed unevenly. The different gravity values influence the geoid. The geoid is also influenced by the rotational velocity of the Earth. During a change of angular velocity, one may expect the geoid pattern to change. When the angular velocity becomes less, the geoid relief probably flattens and its pattern shifts eastward. If the rotation increases, the geoid relief becomes more accentuated and the geoid pattern shifts westward. One may expect that the rotational speed has changed by changes of mass distributions, probably superimposed with effects of the cyclic changes in the Earth's planetary motions. Three known cyclic changes comprise the obliquity of the ecliptic (period of 40,000 years), eccentricity of the orbit (92,000 years), and precession of the equinoxes (21,000 years). Changes in rotational velocity may have occurred every several thousand years to every several hundred thousand years.

Due credit should be accorded to Morner (1976) who pointed out the importance of the geoid for shoreline studies. Before that, many sea-level researchers attempted to correlate former shorelines within and among geologically stable regions solely by their elevations. The current geoid highs and lows define maximum total relief reaching almost 200 metres (see map by Rapp, 1974). Morner argues that the geoidal pattern can change within a short time, perhaps within less than a thousand years.

I propose that during a change to lower rotational speed of the Earth, the geoid pattern may be expected to shift eastward. The newly acquired geoid pattern will be maintained after the change in velocity ceases to operate. In this case, Sumatra and the Thai-Malay Peninsula that lie close to the current zero geoid contour may be expected to experience a drop in sea level, while at the same time the east coast of Argentina experiences sea level rise.

4. Human Activities

Human activities have certainly influenced the nature and rates of erosion, sedimentation, and isostasy. Direct influences include land reclamation, dredging and mining the sea floor, dumping refuse, and excavation of interoceanic waterways. Since the beginning of the industrial revolution, burning of fossil fuels has added 20 per cent to the concentration of carbon dioxide in the atmosphere (Titus, 1986). This gas absorbs infrared radiation resulting in global temperature increase. Long-term tidal records indicate that sea level has already risen 10 to 15 cm during the past century. In the past 15 years concentrations of nitrous oxide and chlorofluorocarbons (from aerosols) have also been increasing. These so called greenhouse gases are warming the Earth, causing expansion of seawater and melting of glaciers. Projections of future sea-level rise have been made, e.g. by Hoffman *et al.* (1983). The actual rise of sea level on a particular coast will be the net result of a combination of factors, that is:

a. global warming of ocean waters.

b. tectonic mobility/stability of the coast.

c. change (?) of the geoid as consequence of mass redistribution (glacier load converts into seawater).

d. change (?) in marine conditions (currents, tides).

e. secular change of regional sea level due to unknown causes (see the case for Peninsular Malaysia).

SHORELINE INDICATORS IN THE MALAY-THAI PENINSULA

Sea-level indictors

Figure 2 summarises sea-level indicators that have been used in studies of former shorelines in Southeast Asia. Shorelines are indicated by certain geomorphic and sedimentological features that may be accompanied by biogenic indicators. The current tidal range on the peninsula's shores is commonly around 2 metres. For want of data, it is assumed that during different sea-level stands of the past 10,000 years, the tidal range remained the same.

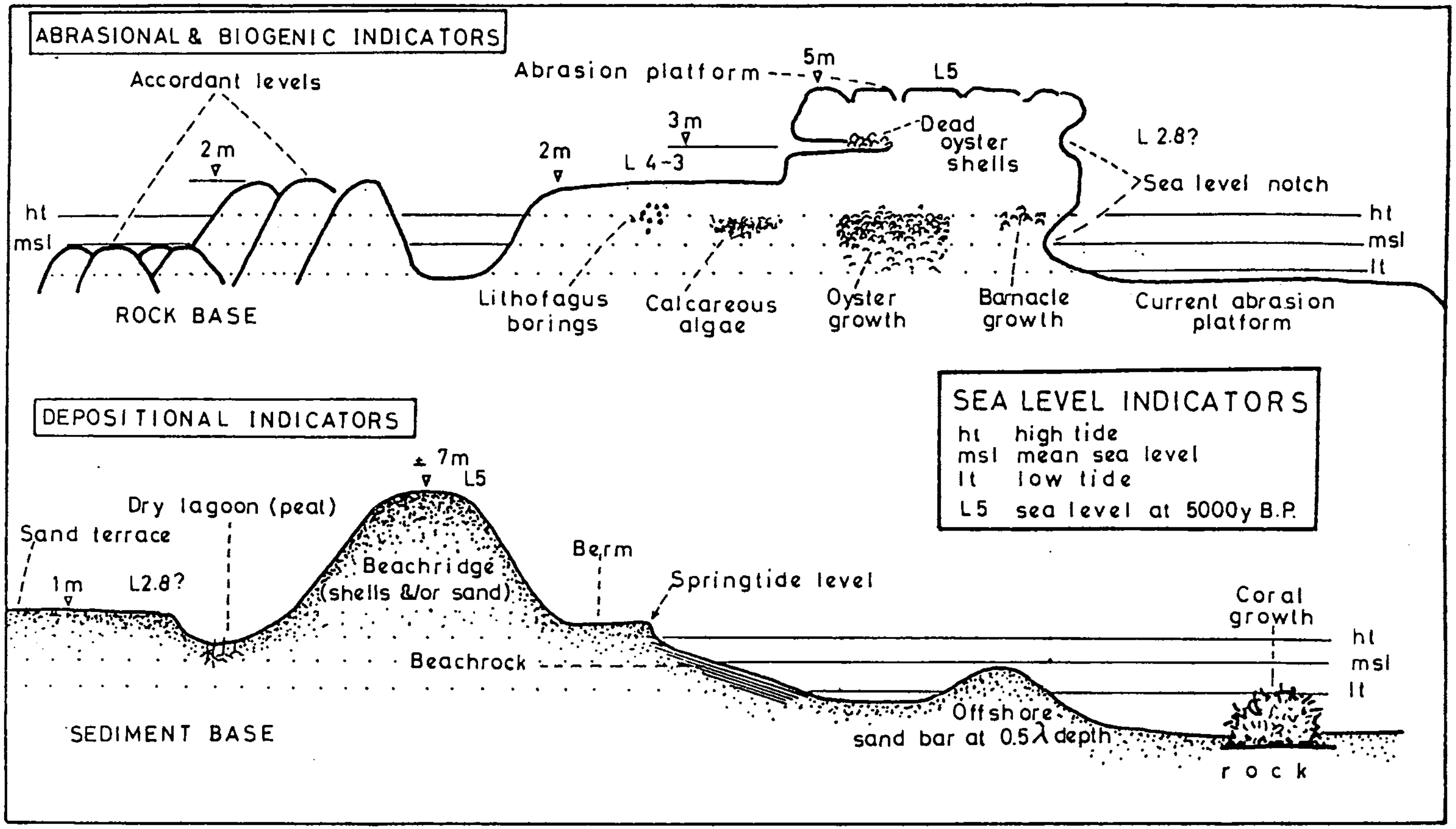

Figure 2: Shoreline indicators in the Malay-Thai peninsula.

Abrasional and biogenic indicators - These indicators are schematically shown in Figure 2. Accordant summit levels of boulders and small sea stacks composed of bedrock are present along certain shores. In the Malay-Thai peninsula, the bedrock may be granite, hard metasedimentary rock, or sometimes also crystalline limestone. These accordant levels very probably represent the approximate position of past mean sea-levels.

Abrasional platforms also occur upon similar rock types. Current abrasion platforms have been observed to occur at or just below low tide level. The platforms may be level or may slope very gently seaward. Raised platforms seldom exceed 10 metres in width. Platforms above 2.5 m elevation generally display effects from subaerial exposure; those platforms are irregularly pitted and often carved up into segments bounded by narrow gullies. It is probable that some of the accordant levels represent remnants of former abrasion platforms.

Sea-level notches are developed in limestone cliffs. In cross-section a notch resembles a recumbent letter U. concave towards the sea. The deepest part of the notch corresponds with mean sea level. The height of notch openings depend on the strength of incoming waves and the tidal range. Low openings indicate calm water surfaces. On the Mersing shore were observed elevated notches in cliffs of metavolcanic rocks, evidence that abrasion rather than solution was the cause.

A number of biogenic indicators have been used in the study. As far as I know, identification and radiometric dating of former shorelines using dead oyster clusters in growth position have been carried out most extensively in Peninsular Malaysia. Live rock-clinging oysters are in the tidal zone, where most oyster species seem to prefer the upper part of the zone. Calcareous algal crusts were also found to correspond with the upper part of the tidal range. In my experience, clusters of dead oyster shells and algal crusts of former sea stands are only preserved in recesses of rock cliffs where the remains have been protected from rain and sea water. Live barnacles are seen to also prefer the tidal zone; young specimens may be in positions up to a few decimetres above the high tide line. For the region under discussion, no former sea levels have been identified by (dead) barnacles. Small holes, about a centimetre across or smaller, drilled horizontally into rocky sea cliffs of limestone have been found to extend up to 30 cm above the high tide line. Past shorelines indicated by these Lithofagus borings have been found empty and until today this sea-level indicator has not been radiometrically dated.

Coral reef platforms develop at positions similar to that of abrasional platforms. Some coral species may withstand subaerial exposure of a few hours during low tides, but generally live corals reach up to low-tide level only. It is widely accepted that reef coral growth flourish in the upper 20 metres of sea water. The few coral dates of former shorelines of the peninsula are within the range of those identified by oyster clusters. In other words, these particular corals indicate the upper part of past tidal zones.

Depositional Indicators – Where nearshore conditions allow, sand accumulates as a beach that extends seaward as sandy seafloor. This sandy seafloor may be extensive and upon regression become exposed as a wide sand terrace along the coast. Offshore bars develop at wave base level in the nearshore. Some researchers suggest that offshore bars migrate landward and may become beachridges. In any case, present-day beachridges on the peninsular coasts are associated with storm waves. On the east coast the ridge crests may build up to 3 metres above high tide; along the west coast bordering Strait Malacca beachridge crests hardly reach a metre above high tide level. The difference in heights reflect the difference in strength of storm waves. Beachrock consisting of calcareous matter cementing calcareous and non-calcareous clasts alike into pavement-like slabs occur along certain stretches of tropical beaches. The rock develops within the tidal zone. Under certain weather condition hardening of calcareous beachrock may take only a few hours. Wind-stress markings within a calcareous beachrock and upon its surface have been described recently by Anizan Isahak (1989). Ferruginous beachrock may also indicate former shorelines. On the southeast Johor coast, large and small boulders of metasedimentary rock cemented into beachrock by blackish Fe-Mn(?) compounds are observed in association with raised abrasional benches (Anizan Isahak, personal communication).

SEA LEVEL CHANGE IN THE MALAY-THAI PENINSULA

Southeast Asia *sensu lato* is composed of two geologically stable regions, in the west the so-called Sundaland and in the east the Sahul Platform, separated by a broad, geologically highly mobile region (Figure 1). The mobile region is characterized by high topographic relief, active volcanos, strong and frequent earthquakes, and rates of vertical crustal movements reaching values of 10 mm/yr. In contrast, the geologically stable regions have experienced very slow vertical crustal movements at rates 2 to 3 orders lower than for the mobile region.

Actual sea level changes can be interpreted for Peninsular Malaysia, Thailand and adjacent areas. This is because the region is part of geologically stable Sundaland and contains many Late Quaternary shorelines dated by the radiocarbon method.

Holocene shorelines in Peninsular Malaysia

More than one hundred and fifty radiometrically (radiocarbon method) dated shoreline indicators in tectonically stable Peninsular Malaysia indicate that prior to 5,000 y. B.P., sea level rose from its low position (a hundred metres or more below present datum) at rates between 15 mm and 6 mm annually to its maximum mid-Holocene (approx. 5,000 y. B.P.) position about 5 metres above mean sea level. Subsequently, sea level receded to its present position through a series of fluctuations of progressively lower peaks and depressions. A lower peak occurred at around 2,800 y. B.P. At around 1,200 y. B.P., Holocene sea level appeared to have dropped one to two metres below current datum. During most of the past millenium, sea level in Peninsular Malaysia was probably 1.5 to 1.7 m above present mean sea level. The Late Holocene fluctuations had approximately 2-metre amplitudes with periods of 2,000 years (Figure 3).

Figure 3 shows about a hundred radiometrically dated shoreline indicators on the coasts of Peninsular Malaysia. The two bold undulating lines envelop most of the shoreline data points. Site and sample descriptions of the dated shoreline indicators are listed in the papers given as references, and many are also published in the inventory of Quaternary shorelines of the Pacific and Indian Oceans edited by Yoshikawa (1987). In Figure 3, vertical lines indicate the range in elevation possible for the particular data point. Arrows indicate that the position of the sample point is lower (arrow points upward) or higher (arrow points down) than the corresponding sea level. Four data points older than 6,500 y. B.P. clearly lie outside the envelope; their implications will be discussed below.

Figure 3 suggests that current sea level is at the peak of one of the fluctuations and that it will recede in the near future at rates between 1.5 mm and 2 mm annually. In the Southeast Asian region, this sea-level drop is expected to lessen the impact of its projected rise resulting from global warming due to the increase of the so-called greenhouse gases in the atmosphere.

Holocene Shorelines in Thailand

In Thailand, until today almost a hundred radiometrically dated Quaternary shoreline indicators have been published (Sinsakul *et al.*, 1985; Sinsakul, 1990; Engkagul & Pramojanee, 1991). Most of these dates are from Thailand's peninsular coasts. The reliable indicators comprise mainly peat (sometimes identifiable as basal peat), marine shell deposits and mangrove wood. In contrast to Quaternary shoreline data from Peninsular Malaysia, only two indicators of rock-clinging oyster type molluscs have been dated. Both samples are associated with sea-level notches in Permian limestone on Kaew Island in Phang Nga Bay (Figure 4). Several 5,000 to 7,000 year old, marine shell deposits at elevations between 5 and 10 metres have been radiometrically dated. All such deposits are in caves and archaeologists believe these to represent middens. Geologists have countered that such shell deposits occur extensively all along the west coast from Phang Nga to Satun. Several deposits exhibit good stratification and are associated with abrasion platforms and notches. Geologists (among them Sinsakul) think the deposits to have been formed by storm surges when past sea level was also higher.

Figure 5 shows the radiocarbon ages and elevations of Holocene shorelines in Thailand. Vertical lines indicate the possible error in elevation of a data point; horizontal bars indicate the uncertainty of radiocarbon ages. The position of three peat samples (a, b and c) lie outside the diagram. T and R at the bottom of the figure represent transgressive and regressive periods. The numbers +4, +2.5 and +2 indicate maximum sea stands in metres above mean sea level during the

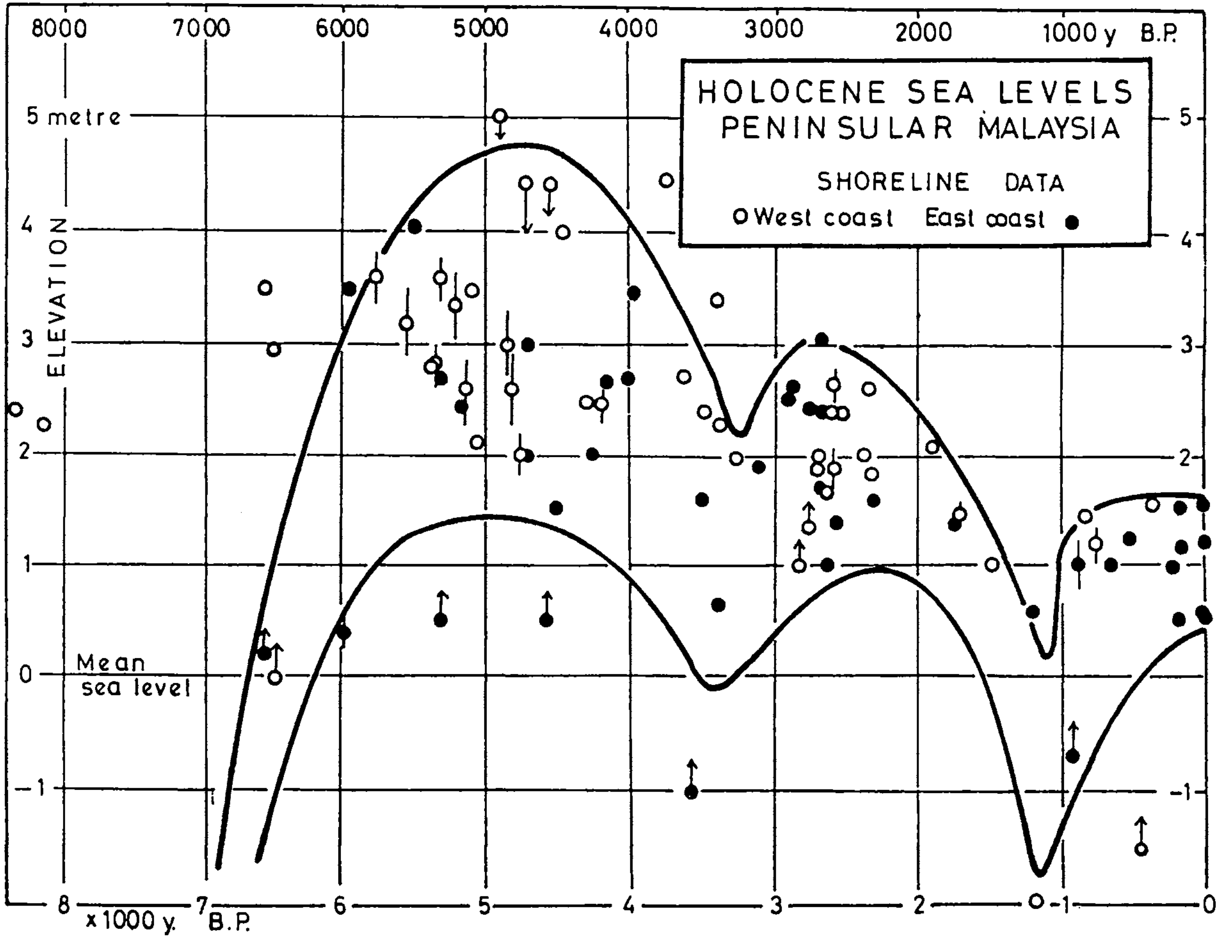

Figure 3: Sea level trend in Peninsular Malaysia since 6500 BP. The envelope contains most of the shoreline data. The boundaries of the envelope are drawn about midway between the few extreme data points and their neighbouring data points within the envelope. From H.D. Tjia & S. Fujii (1989).

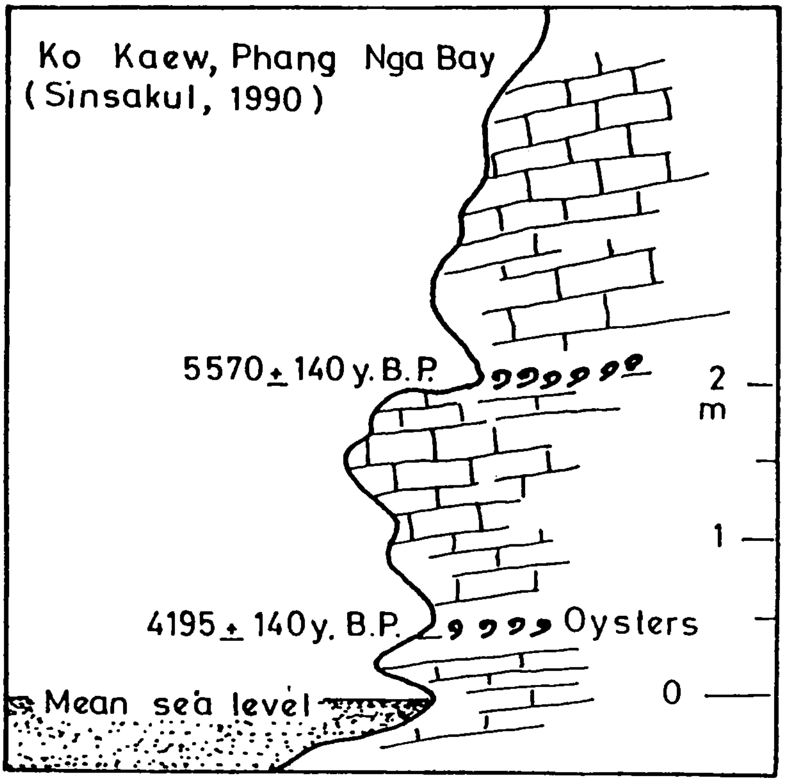

Figure 4: Rock-clinging oysters and stacked sea-level notches in a limestone cave at Ko Kaew, Phang Nga Bay, Thailand (after Sinsakui 1990).

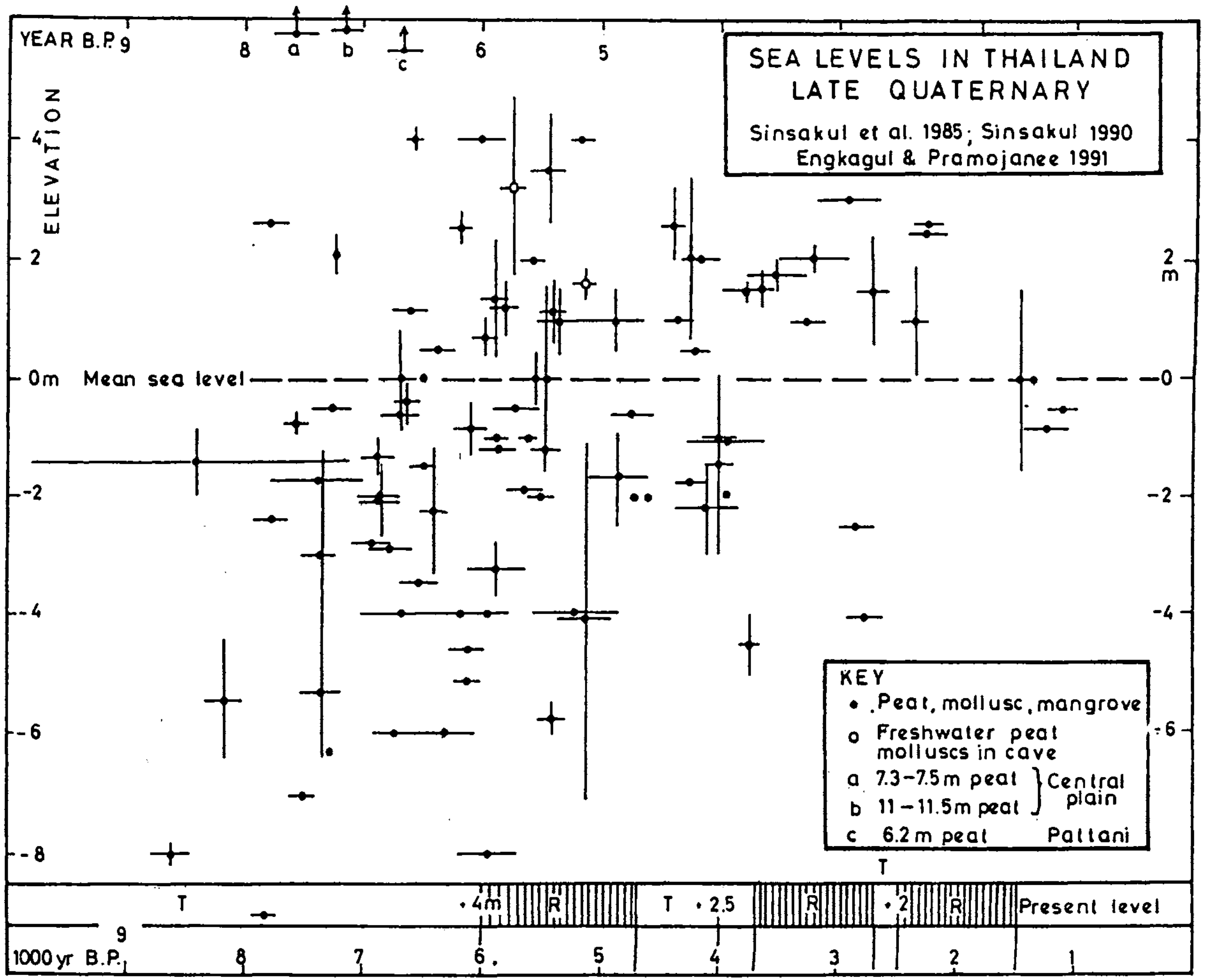

Figure 5: Positions of Holocene sea levels in Thailand.

various transgressions. Sinsakul (1990) proposed a currently accepted history of sea level changes during the Holocene of Thailand.

After the lowest sea level stand during the peak of the Last Glacial, sea level rose steadily from a position far below present datum to reach about 4 metres above it at around 6,000 y B.P. The sea then subsided until 4,700 y. B.P. The succeeding trangression reached a new peak of 2.5 m above mean sea-level around 4,000 y. B.P. This was followed by a regressive period between 3,700 and 2,700 y. B.P. of which many data points fall below present datum. Between 2,700 and 2,500 y. B.P. another transgression took place culminating at 2 m above mean sea-level. The succeeding regression brought sea level down until it reached present datum around 1,500 y. B.P., and apparently stayed at that elevation until today.

Problematic Holocene sea-level positions

Four Early Holocene (6,500 y. B.P. and older) shoreline indicators from the Langkawi islands lie distinctly outside the envelope of sea-level changes (Figure 3). From Kodiang, that is also located in the northwest part of Peninsular Malaysia, were dated 21 ka and 27 ka shore elevations that are as much as 40 metres higher than corresponding sea-levels in the southern part of Malacca Strait (see Geyh *et al.*, 1979). At those times, elsewhere in the world sea-levels were definitely below current datum (see Chappell & Shackleton, 1986). Recently, a stratigraphic section at Pantai Remis, some 240 km to the south of Kodiang, was interpreted to correspond with relatively higher seas at around 29 ka ago.

Kodiang Hills, Northern Perak

In a cave of Bukit Hantu, one of seven crystalline limestone hills at Kodiang, marine shells and shell debris formed (now destroyed by guano extraction) cemented layers. The elevation ranged from 10.35 m and 8.7 m above mean sea-level. Samples of the top and bottom limits are 26,840 ± 1,540 y. B.P. (sample GaK-11,207) and 21,070 ± 890 y. B.P. (sample GaK-11,028; see Tjia, 1987). The Kodiang hills lie more than 15 km from the present shoreline and stand on a wide coastal plain that is 4.8 m above mean sea level. Bukit Hantu and the other hills also exhibit several stacked notches at these and at lower levels.

At 27 ka and 21 ka sea level in the southern part of Strait Malacca was about 35 m and at least 40 m below present datum (Geyh *et al.*, 1979; Tjia, 1991). Chappell & Shackleton's (1986) sea-level curve of the Late Quaternary also shows similar values. The anomalous position at Kodiang could indicate average annual rates of uplift of 1.5 mm and 2.3 mm, respectively. Or, the geoid had that much relief between the north and south parts of Strait Malacca.

Pantai Remis, Southern Perak

At Pantai Remis, marine shelly sand at 1.5 m below mean sea level was dated at 480 ± 120 radiocarbon years (Mazlan Madon & Kamaludin Hassan, 1991).

This Holocene marine deposit rests unconformably upon palaeosol, a hardened humic sand that is 28,900 ± 300 radiocarbon years old. At that time, elsewhere in Southeast Asia, sea-level was at least 30 m below present datum (Geyh *et al.*, 1979; Tjia, 1991). Mazlan and Kamaludin believe that the high position of this palaeosol was due to crustal uplift that kept pace with or was faster than the rise of sea level.

An alternative explanation could be that the palaeosol developed at the elevation it is now and that a large part of marine deposits resulting from the widespread mid-Holocene transgression had been abraded and eroded.

Langkawi Islands, Northwestern Kedah

Dated samples GaK-5289 (8,320 ± 160 B.P.) and GaK-5288 (9,510 ± 185 B.P.) consist of corals attached to lower Palaeozoic limestone at positions 2.4 m and 3.4 m above mean sea-level at Kuala Kubang Badak on the north coast of main Langkawi Island. At those times sea-level in the southern Strait Malacca was - 20 m and approximately - 40 m (Geyh *et al.*, 1979; Tjia, 1991).

From the north and south tips of Dayang Bunting Island of the Langkawi group of islands, rock-clinging oysters were collected from elevations 3.5 m and 2.3 m above mean sea-level. Their radiocarbon ages are 6,550 ± 80 y. B.P. (sample Beta 16,810) and 8,129 ± 190 y. B.P. (Shoji Fujii, personal communication), respectively. These positions are about 3.5 m and 19 m higher than shorelines of the same ages in the southern Strait Malacca.

If these four shoreline indicators had experienced crustal uplift, their annual rates ranging between 2.8 mm and 9.5 mm would qualify the Langkawi island group as a tectonically mobile area, comparable to eastern Indonesia. No geological features such as earthquake epicentres, young volcanism, high local relief between land and seafloor, or raised Cenozoic deposits are known from Langkawi. Only one occurrence of presumably Quaternary, shell deposit was reported by Jones (1976) at "30 feet" elevation on the east shore of Kuala Kubang Badak.

Figure 6 shows the raised oyster cluster at Teluk Air Taun, south tip of Dayang Bunting Island. A sample from the topmost part indicates the anomalous position of sea-level at 8 ka. However, samples from 2 m and 1.3-1.4 m elevations have ages that fall within the envelope of sea-level changes of Figure 3. The radiocarbon ages were personally communicated by S. Fujii of Toyama University, Japan.

Fourteen other shoreline indicators younger than 5.3 ka representing the entire Langkawi island group (Tjia & Fujii, 1989) all fall within the envelope. If crustal uplift was the cause of anomalously high positions of strandlines older than about 6.5 ka in Langkawi, since then relative crustal stability must have prevailed to account for the normal positions of post Mid-Holocene shorelines, such as illustrated by Figure 6 and dated shores elsewhere in the island group (see Tjia & Fujii, 1989).

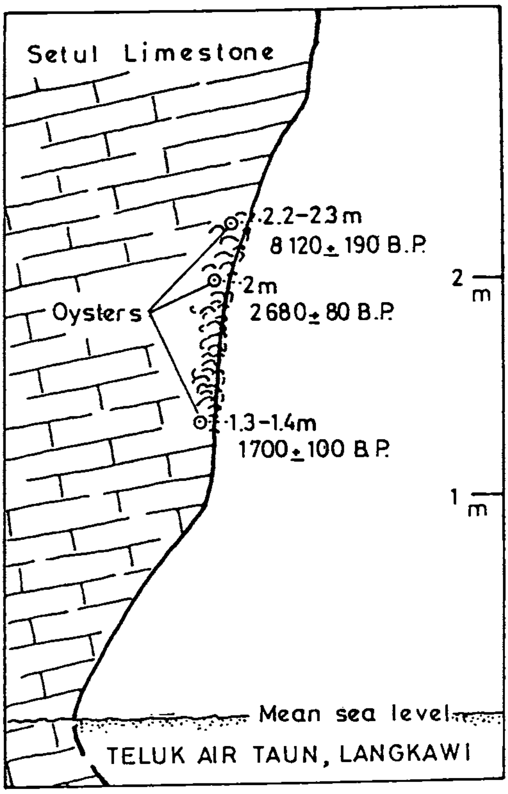

Figure 6: Rock-clinging oysters on a limestone cliff at Air Taun Bay, Dayang Bunting Island of the Langkawi group. The elevation of the 8 ka oyster shells is anomalous on Figure 3.

The probability is very low for rapid crustal uplift in Peninsular Malaysia at rates comparable to those measured in tectonically mobile areas, even taking into consideration that the localities with anomalously high sea levels are near the edge of stable Sundaland. I find more attractive the possibility that in the 27 ka - 21 ka period and during the Early Holocene before 6.5 ka, geoids were up to 40 m higher in the north compared to those in the south of Strait Malacca. The Early Holocene high geoid may have extended as far north as Phang Nga Bay where up to 10 m high Holocene (one was dated at 5.7 ka, Sinsakul, 1990) shell deposits are sometimes associated with sea notches.

CONCLUSIONS

(1) Holocene sea-level in the Malay-Thai peninsula exhibits similar behaviour after about 6.5 ka.

(2) In Peninsular Malaysia and Thailand, sea-level peaked at 5 m elevation 5 ka ago and at about 4 m elevation some 6 ka ago, respectively.

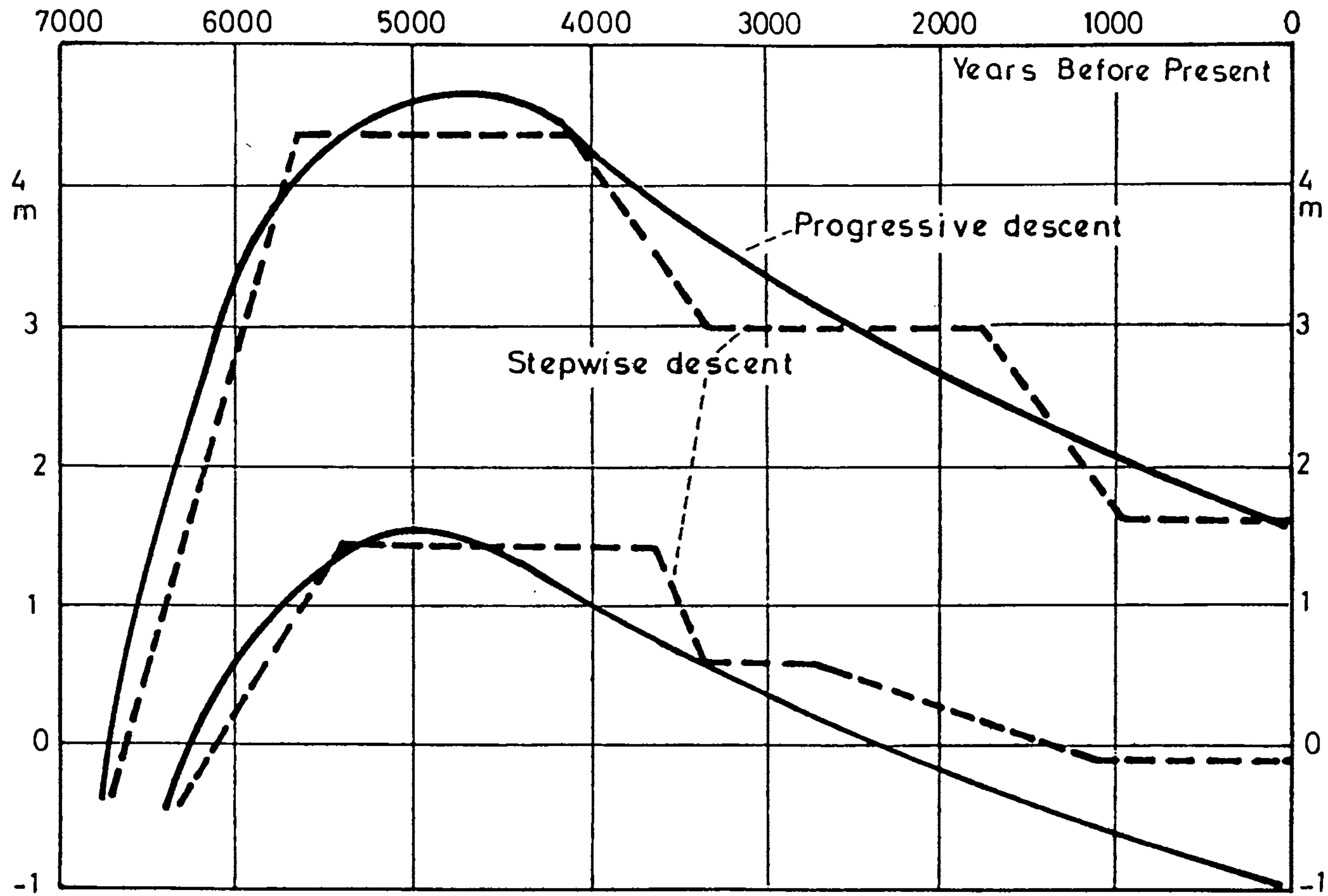

Figure 7: Two other possibilities of trend in sea level changes based on a hundred published data points from Peninsular Malaysia. One alternative is progressive but gradual decrease of sea level after the mid-Holocene peak; the second alternative is stepwise descent of sea level with long periods of stillstand.

(3) From this maximum mid-Holocene position, sea-level probably descended in a series of short to medium long periods (hundreds to 2,000 years) of regressions and transgressions.

(4) One of the regressions depressed sea-level below present datum. This occurred between 3.7 ka to 2.7 ka in Thailand, and around 1.2 ka in Peninsular Malaysia.

(5) The data points of sea-levels of the entire peninsula may represent only one peak at 4 m to 5 m elevation in the Mid-Holocene, followed by gradual decline. Another alternative is that after the Mid-Holocene peak, sea-level descended stepwise (Figure 7).

(6) There is evidence for Peninsular Malaysia that until a few hundred years ago sea-level may have been some 0.5 m higher than today.

(7) In Thailand, present datum was reached 1,500 y. B.P.

(8) There is strong evidence that during the Early Holocene and a Late Quaternary period between 27 ka and 21 ka, the geoids in the northern part of Strait Malacca from the latitudes of Langkawi (6°40'N) to Phang Nga (8°N) were much higher than in the southern Strait Malacca. The geoidal relief reached at least 40 metres in each period.

REFERENCES

ALVAREZ, L.W., 1987. Mass extinctions caused by large bolide impacts. *Physics Today* 40 (7): 23-33.

ANIZAN ISAHAK, 1989. Wind-stress features and their paleoenvironmental implication in the East Coast of Johor. *Sains Malaysiana* 18 (1): 13-22.

Chappell, J. & N.J. Shackleton, 1986. Oxygen isotopes and sea level. *Nature* 342: 137-140.

ENGKAGUL, V. & P. PRAMOJANEE, 1991. The correlation of Holocene sea level change along the east coast of Peninsular Thailand. IGCP-296 Workshop on Quaternary of Asia and the Pacific, Phuket, Thailand. 20-21 October 1991: 11 pp., 8 figs, 1 table.

GEYH, M.A., H. KUDRASS & H. STREIF, 1979. Sea-level changes during the Late Pleistocene and Holocene in the Strait of Malacca. *Nature* 278: 441-443.

Geological Survey Division, 1983. Geological map of Thailand, 1: 500,000. Department of Mineral Resources, Bangkok, Thailand: 5 sheets.

Geological Survey of Malaysia, 1985. Geological map of Peninsular Malaysia, 8th edition, 1:500,000. Geological Survey of Malaysia, Kuala Lumpur: 2 sheets.

HOFFMAN, J.S., D. KEYES & J.G. TITUS, 1983. Projecting future sea level rise. U.S. GPO # 055-000-0236-3, Washington, D.C., U.S. Government Printing Office.

JONES, C.R., 1978. The Geology and Mineral Resources of Perlis, North Kedah and the Langkawi Islands. *Geological Survey of Malaysia, Memoir 17:* 257 pp.

KAMALUDIN HASAN & YUNUS ABDUL RAZAK, 1991. Significance of Quaternary geology studies in the coastal areas. Proceedings IEM/ICE Joint Conference on Coastal Engineering in Nationa Development, Kuala Lumpur March 1991: B1-B30.

MAZLAN MADON & KAMALUDIN HASSAN, 1991. Quaternary deposits near Pantai Remis, NW Peninsular Malaysia, and significance of the Pleistocene-Holocene unconformity. IGCP-296 Workshop Quaternary of Asia and the Pacific, Phuket, Thailand, 20-21 October 1991: 5 pp., 10 figs.

MORNER, N.A., 1976. Eustasy and geoid changes. *Journal of Geology* 84 (2): 123-151.

RAPP, W.H., 1974. Current estimates of mean earth ellipsoid parameters. *Geophysical Research Letters* 1 (1): 35-38.

SINSAKUL, S., 1990. Evidence of sea-level changes in the coastal area of Thailand: a review. CCOP-UNEP Workshop on Global Environmental Change, Chiangmai, Thailand. 2-7 July 1990: 30 pp.

SINSAKUL, S., M. SONSUK & P.J. HASTINGS, 1985. Holocene sea-levels in Thailand: Evidence and basis for interpretation. *Journal Geological Society of Thailand,* 8 (1-2): 1-12.

TITUS, J.G., 1986. The basis for expecting a rise in sea-level. *In:* C.H.J. Hull, *et al.* eds. "Greenhouse effect, sea-level rise and salinity in the Delaware Estuary. U.S. EPA, Delaware River Basin Committee, EPA 230-05-86-010: 3-14.

TJIA, H.D., 1970. Rates of diastrophic movement during the Quaternary in Indonesia. *Geologie en Mijnbouw* 49 (4): 335-338.

TJIA, H.D., 1987. Ancient shorelines in Peninsular Malaysia, SPAFA Final Report "Seminar in Prehistory of Southeast Asia", Thailand, 15-25 January 1987: 239-257.

TJIA, H.D., 1989. Active tectonics in the Indonesian archipelago. Proceedings Workshop of Quaternary Stratigraphic Correlation (IGCP 218), Bangkok, 21-24 November 1988: 165-185.

TJIA, H.D., 1990. Global warming and long-term sea-level change in Southeast Asia. *Sains Malaysiana* 19(1): 75-89.

TJIA, H.D., 1991. Trend of sea-level change in Peninsular Malaysia. Proceeding IEM/ICE Joint Conference "Coastal Engineering in National Development", Kuala Lumpur, 4-6 March 1991: B31-B47.

TJIA, H.D., S. FUJII & K. KIGOSHI, 1977. Changes of sea-level in the southern part of the South China Sea area during Quaternary times. *United Nations, ESCAP-CCOP, Technical Bulletin* 5: 11-36.

TJIA, H.D., & S. FUJII, 1989. Late Quaternary shorelines in Peninsular Malaysia. International Symposium on Coastal Evolution, Management, and Exploration in Southeast Asia, IGCP 274, Ipoh, Malaysia, 4-10 September 1989.

YOSHIKAWA, T., editor, 1987. *Inventory of Quaternary Shorelines. Pacific and Indian Oceans Region.* Nodai Research Institute, Tokyo: 130 pp.

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